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**THE SELECTION, DESIGN, AND OPERATION
OF LARGE COMBUSTION EQUIPMENT
TO BURN CAPE BRETON COAL**

by

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E. R. Mitchell* and F. D. Friedrich**

INTRODUCTION

In the past three years the Fuels and Mining Practice Division of the Mines Branch has directed an active research program to improve combustion of Cape Breton coal, particularly with stoker firing, but also with pulverized firing. It became obvious that some firing systems are inherently better able to deal with the difficult characteristics of the coal, and it is therefore possible to recommend that these systems be selected for new plants. Furthermore, extensive experiments have been carried out; on laboratory apparatus, on many types of full-scale industrial stokers, and on large pulverized-fired steam generators. Ways were found to improve performance of the coal by redesigning or modifying grates, systems of coal and combustion air distribution, over-fire turbulence and auxiliaries. Considerable data have been compiled which are valuable both in the design of new plants, and in the modification and operation of existing ones.

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In this report the principal properties of Cape Breton coal influencing combustion are discussed and recommendations are made concerning selection, design and operation of large equipment to burn it successfully. Although many of these recommendations apply equally well to small combustion equipment, those given here deal primarily with combustion equipment capable of burning 500 lb of coal per hr or more. Equipment burning under 500 lb of coal per hr is dealt with in a companion report entitled "The Design and Operation of Small Combustion Equipment to Burn Cape Breton Coal".

INFLUENCE OF PRINCIPAL COAL PROPERTIES ON COMBUSTION

General

Coal is such a complex fuel that its many physical and chemical properties cannot be explained in detail here. Instead, only brief reference is made to those having the greatest influence on combustion, and on design of stoker and pulverized firing equipment.

While Cape Breton coal is mined from many different seams, its properties are fairly uniform, except for the free-swelling index. In this regard coal from the Harbour and Phalen seams, producing the mixture called "Dominion", is highly caking, having a free-swelling index of 8 to 9, while coals such as "Four Star" and "Indian Cove", from the Tracey and Upper Jubilee seams, are only moderately caking, having a free-swelling index of 4 to 6.

The latter coals have a lower ash fluid temperature, and often a lower ash softening temperature, than Dominion, but it has been shown that the ash softening temperature of Cape Breton coal is as much as 400°F higher in an

oxidizing atmosphere than in a reducing atmosphere. Thus, because a moderate caking tendency permits oxidizing conditions to prevail in the fire-bed, it is often possible to tolerate the low ash fusion temperature of the coals having a low to moderate free-swelling index.

A typical analysis of Dominion has been used for the coal specification and combustion calculations in this report, both because it is the largest mined tonnage of Cape Breton coal, and because experience has shown that equipment designed to burn Dominion will handle the more free-burning coals equally well, in spite of higher ash content and lower ash fluid temperature.

Stoker Firing

On ignition, highly caking Cape Breton coal such as Dominion swells and agglomerates into plastic masses which cake into strong, massive formations as the volatiles are driven off. Because these cakes are impervious to penetration by combustion air and difficult to break into smaller pieces, the strong caking property of the coal has the greatest influence on general selection and detail design of suitable stoker equipment.

The coke produced is very reactive, and burns so intensely that fire-bed temperatures are very high, therefore the ash content and its low fusion temperature become the next important consideration. If the ash reaches slagging conditions it runs into dense clinkers which block grate air openings, thereby curtailing or stopping combustion. While this cools the grate it also reduces boiler steaming capacity.

The tendency of a coal to smoke is proportional to its volatile content, and volatile content therefore influences design of the overfire turbulence system as well as of the stoker and furnace. Caking of the coal and clinkering of the ash both contribute to excessive smoke by interfering with combustion air distribution, but Cape Breton coal can be burned relatively smokelessly by providing control of both coal and combustion air distribution and by maintaining thin fires.

Coal size is also a consideration in both handling and burning. The amount of free moisture the coal absorbs and retains is important in handling, for although moisture may perform a useful function by increasing porosity of a fire-bed and reducing burning rate, it causes the fine sizes of coal to pack and block in conveying and feeding devices. Double-screened coal does not pack so readily when wet and this is one reason it is often selected for conventional stokers. Furthermore, where coal is burned in thick beds, as in underfeed stokers, a double-screened coal provides a more porous fire-bed than a nut-slack coal and the resulting free air penetration minimizes both caking and clinkering.

Finally, because part of the sulphur in the coal is burned to dangerously corrosive SO_2 and SO_3 , care must be taken in boiler design and in stoker operation to ensure that flue gases do not cool to the dew point temperature. However, much of the sulphur is trapped or fixed in the ash, and this amount can be increased by simple additives.

Pulverized Firing

Pulverized firing systems are unaffected by many of the foregoing difficult properties, and furthermore, benefit from several properties which have made Cape Breton coal generally popular for burning in suspension.

Probably the properties most favourable to burning in suspension are its high reactivity and ignitability. Reactivity is understood to be a measure of the rate of reaction between the fuel and oxidizing medium, while ignitability is a measure of the ease with which the coal may be brought to self-supporting combustion. As yet there is neither an acceptable laboratory index of reactivity nor a direct correlation between reactivity index and physical properties or burning characteristics.

Another favourable property is the high grindability index, particularly of the fine sizes or slack normally used for pulverized firing.

Although surface moisture assists the combustion process, it can impede handling, and adds to the drying and grinding load of a pulverizer mill. If excessive, it can reduce rate of ignition, and therefore, firing rate.

With pulverized firing, sulphur in the coal is burned almost completely to corrosive SO_2 and SO_3 , and passes through the boiler, raising the gas dew-point temperature. Unless care is taken in boiler design, serious damage can result.

The low ash fusion temperature can present a problem of slag deposition on boiler heating surfaces. To avoid it, dry pulverized systems should have radiant furnaces with low heat release rates and low gas velocities. In recent years slagging combustion chambers have minimized this problem by

draining off about 85% of the ash as slag before it has an opportunity to enter the main furnace or boiler passes.

While coal structure, oxygen, hydrogen and volatile content affect combustion performance, they generally contribute to the favourable reactivity and ignitability of the coal, and will not be discussed further.

COAL SPECIFICATION

Table 1 gives the coal specification recommended for use in designing large stoker-fired equipment to burn Cape Breton coal. The figures have been drawn from The Analysis Directory of Canadian Coals and Supplement,^{1/} which provides reliable specifications for all Canadian coals. For the reasons explained on page 3, the specification is that for Dominion coal, but most of the other Cape Breton coals fall within the given range, except with regard to free-swelling index. Because a new coal-burning plant should be designed to handle the poorest quality of coal normally available in the area, 3/4 in. x 0 slack has been specified.

^{1/} E. Swartzman and T.E. Tibbetts, Analysis Directory of Canadian Coals, Department of Mines and Technical Surveys, Report No. 836 and Supplement No. 850.

TABLE 1

Coal Specification for Stoker Design

Dominion Slack, 3/4 in. x 0				As Received	Range to be Expected at Some Distance From Sydney or Montreal	
<u>Proximate Analysis</u>						
Moisture	%		5.5	1.5 to	10.0	
Volatile Matter	%		30.7	30.7 to	39.3	
Fixed Carbon	%		53.5	46.1 to	58.8	
Ash	%		10.3	3.6 to	16.2	
Calorific Value,		Btu/lb	12,640	11,120 to 14,290		
<u>Ultimate Analysis</u>						
Moisture	%		5.5	--		
Ash	%		10.3	--		
Carbon	%		71.0	--		
Hydrogen	%		4.7	---		
Nitrogen	%		1.3	--		
Sulphur	%		2.8	--		
Oxygen (by diff)	%		4.4	--		
Ash Softening Temperature, °F			2,025	1,970 to	2,185	
Free-swelling Index, ASTM			9.0	8.0 to	9.0	
Caking Properties, (volatile matter residue, 950°C)			good	--		
<u>Screen Analysis</u>						
Round Hole Size, in.						
plus	3/4		% by wt	0	0 to 1.2	
3/4	x	1/2		% by wt	13.3 11.3 to 15.5	
1/2	x	3/8		% by wt	9.7 8.8 to 10.1	
3/8	x	1/4		% by wt	13.4 12.5 to 14.4	
1/4	x	1/8		% by wt	19.3 17.1 to 21.0	
1/8	x	1/16		% by wt	15.2 10.5 to 17.2	
1/16	x	1/32		% by wt	12.4 11.8 to 12.9	
minus	x	1/32		% by wt	16.7 15.3 to 18.0	
minus	1/4		% by wt	63.6	58.8 to 67.4	

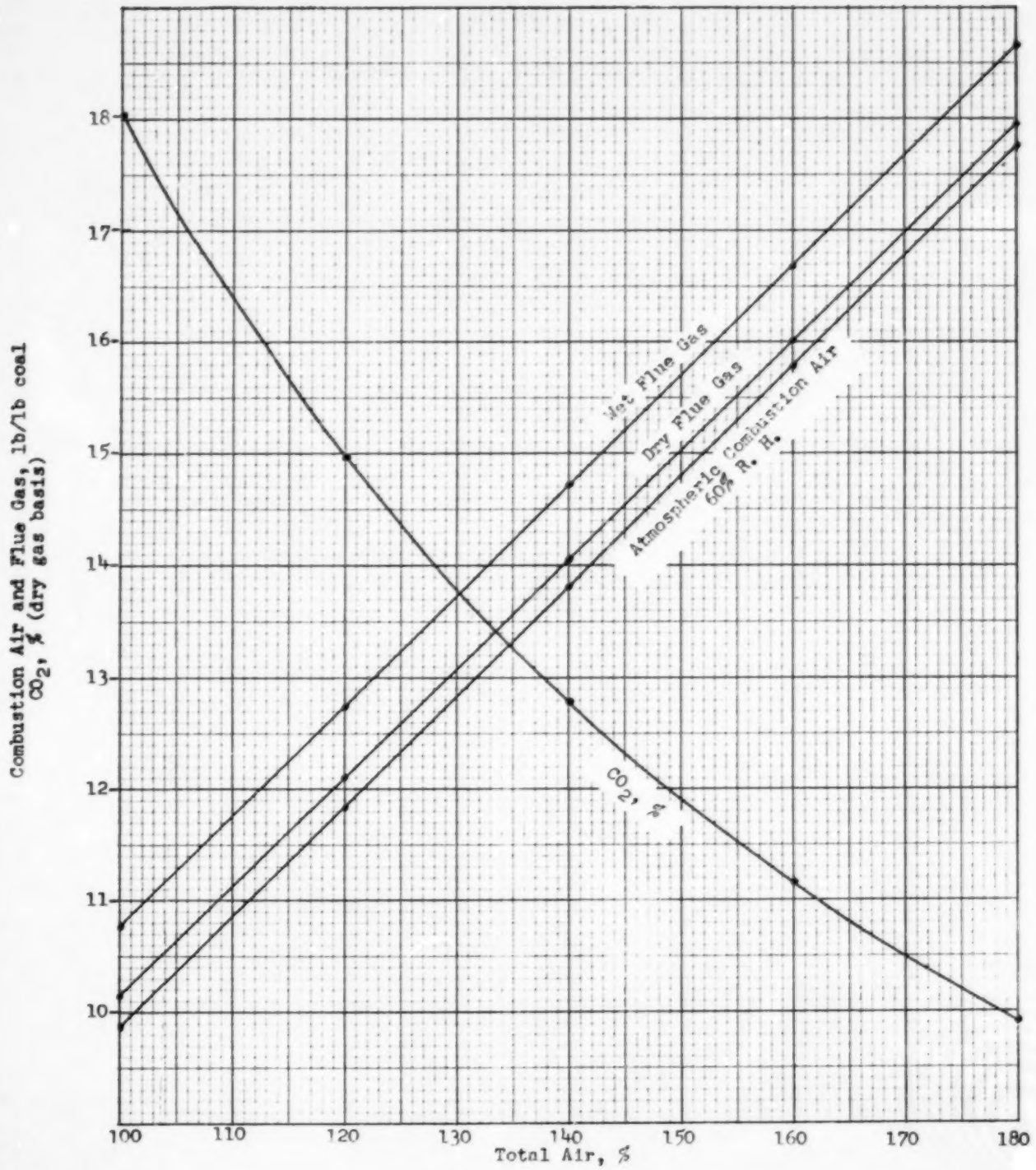


Figure 1 Combustion data for Dominion Slack, 3/4 in. x 0

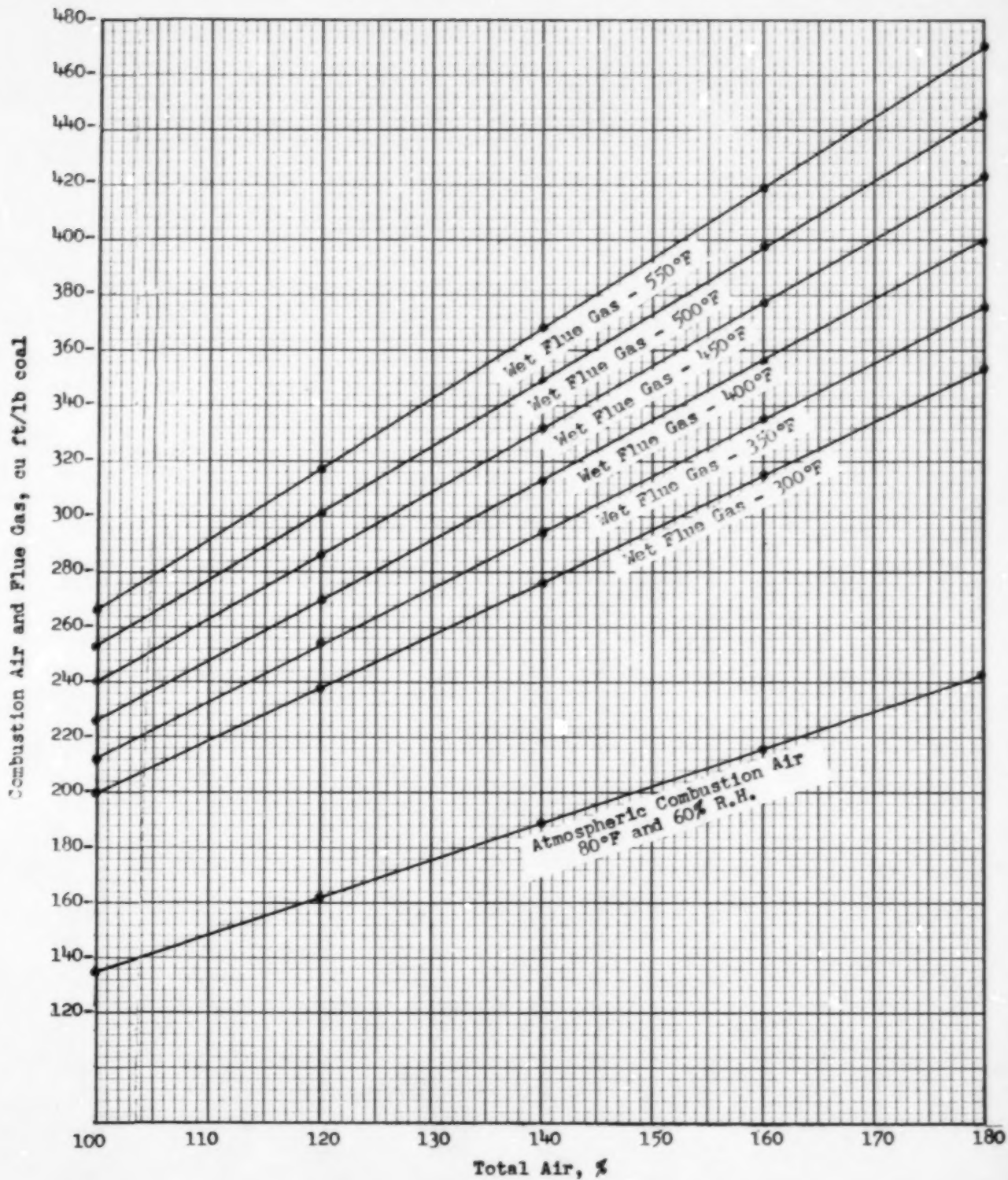


Figure 2 Volume of combustion air and flue gas for Dominion Slack, 3/4 in. x 0

Although the terms "slack" and "nut-slack" are used loosely, the definition commonly used for purchasing coal is that given in the Canadian Government Specifications for Coal, 18-GP-1A and 18-GP-6. However, for design purposes, lower quality coal should be anticipated, therefore, in this report the following definitions common to the trade are used. Slack is coal as mined which passes a 3/4 in. round hole screen. Nut-slack is coal as mined which passes a 1 1/4 in. to 2 in. round hole screen. Thus, nut-slack differs from slack in that it contains some coal between 3/4 in. and 2 in., which is known as "nut" size coal.

COMBUSTION DATA FOR DOMINION SLACK, 3/4 in. x 0

For the convenience of designers of stoker equipment, combustion data for the coal specified above are summarized in Table 2 and Figures 1 and 2. These data are calculated in Appendix I on the "as received" basis with combustion air at 80°F and 60% relative humidity.

TABLE 2

Combustion Data for Dominion Slack, 3/4 in. x 0

Total Combustion Air, %	100	120	140	160	180
CO ₂ %	18.05	14.96	12.78	11.15	9.90
Combustion Air,					
lb/lb coal	9.86	11.84	13.81	15.78	17.76
cu ft/lb coal	135.2	162.3	189.4	216.4	243.4
Wet Flue Gas,					
lb/lb coal	10.76	12.74	14.71	16.68	18.66
cu ft/lb coal ... 300°F	200.4	238.7	277.0	315.2	353.5
cu ft/lb coal ... 350°F	213.6	254.4	295.2	336.0	376.7
cu ft/lb coal ... 400°F	226.8	270.1	313.4	356.7	400.0
cu ft/lb coal ... 450°F	240.0	285.8	331.6	377.4	423.2
cu ft/lb coal ... 500°F	253.2	301.5	349.8	398.2	446.5
cu ft/lb coal ... 550°F	266.4	317.2	368.0	418.9	469.8

RECOMMENDATIONS FOR SELECTION, DESIGN AND OPERATION OF COMBUSTION EQUIPMENT

General

From an understanding of the effects of coal properties on combustion, and their relative importance, the most suitable types of stoker equipment become apparent. On the other hand, only by conducting carefully planned combustion experiments under controlled conditions can reliable recommendations be made for detail design and operation. Extensive tests have revealed the most suitable types of combustion equipment and techniques for their operation. Also revealed were details of design applicable to new equipment, many of which can be applied by modifications to existing equipment, to provide improved performance beyond the limits of the aforementioned operating techniques.

Recommendations for Selection of Stokers

A suitable stoker must provide:

1. Positive coal feed
2. Control of coal distribution
3. Pre-oxidation of coal
4. Continuous ash discharge

At present the first three features are best provided by mechanical spreader firing, and the last may be provided by travelling, oscillating or vibrating grates.

Recommendations for Design of, or Modifications to,
Stoker Equipment and Auxiliaries

5. Control of combustion air distribution should be provided, preferably by zoning dampers under the entire grate.
6. Grate heat release rates should not exceed the following; assuming effective grate area to be the instantaneous area through which air is introduced.

<u>Type of Stoker</u>	<u>Heat Release Rate, Btu/sq ft effective grate area/hr</u>	<u>Burning Rate, lb/sq ft effective grate area/hr (12,640 Btu/lb)</u>
Spreader-fired travelling grate	400,000	31.6
Spreader-fired oscillating grate	375,000	29.6
Spreader-fired dump grate	350,000	27.7
Chain grate	350,000	27.7
Underfeed stoker	350,000	27.7
Water-cooled vibrating grate	400,000	31.6

7. Grate bars or links should be cast in a suitable alloy. While improvement in grate alloys can be expected, one composition already proven suitable for both large and small bars is as follows:

Alloy designation 1% Cr - 1% Ni

Alloy Specification

Carbon	%	3.30 to 3.50
Manganese	%	0.50 to 0.70
Silicon	%	2.40 to 2.60
Sulphur	%	0.15 Max
Phosphorus	%	0.30 Max
Chromium	%	0.80 to 1.20
Nickel	%	0.90 to 1.10

8. Grate air openings should be slots on the edges of bars or links, and self-cleaning, if possible. Air pin holes in the grate surface should be avoided except for a high-resistance grate wherein bars are rigidly bolted together to prevent warping and consequent air leakage between bars.
9. Grate air opening should be no less than 5% of the effective grate area for conventional grates and no less than 3% for high-resistance grates.
10. Grate bars or links should have a massive cross-section to provide adequate heat transfer from the grate surface. Permissible temperature differential between the grate surface and substructure is being determined in field experiments at the time of writing.
11. A non-segregating type of coal hopper is desirable to ensure that coal of a uniform size consist is fed to the stoker. This applies to slack sizes in particular and sometimes to modified coals, for example those which have had the minus 28 mesh size removed. Non-segregating hoppers are usually employed where coal is supplied to large stokers from overhead storage bunkers.
12. An overfire turbulence system should be provided using either high-pressure steam air-inspiring nozzles with sound muffling of the air, or high-pressure air blower jets. Nozzle size and blower pressure depend on conditions of the installation, and may be obtained from BCR Aid to Industry 500-300.^{2/}

^{2/} Application of Overfire Jets to Prevent Smoke From Stationary Plants, BCR Aid to Industry 500-300.

Typical values for 1/2 in. nozzles are:

20 in. water gauge air pressure for 5 ft penetration

40 in. water gauge air pressure for 7 ft penetration.

13. Overfire air should not exceed 5% of the total combustion air because as much air as possible should be introduced through the grate for cooling.

14. Overfire turbulence should cover the entire area producing smoke.

The nozzles should be located 10 to 12 in. above the fire. Thus, with spreader-fired grates the nozzles should be 13 to 15 in. above the grate and for some underfeed stokers they should be 24 to 26 in. above the grate.

15. Furnace exit temperatures should not exceed 1870°F. Otherwise the softening temperature of the ash may be reached, and slagging may occur.

16. Forced and induced draft fans should be selected for 11% CO₂ at the boiler outlet. They should have margins of at least 15% on volume and 30% on pressure when operating at MCR with the specified coal.

17. A high-efficiency dust collector is required. For example, with spreader firing, collection efficiency should not be less than 90% by weight, assuming that 50% of the fly ash produced will pass through a 325 mesh screen, and assuming that the solid material entering the dust collector has the following sizing:

Particle Size, microns (0.001 mm)		Average Size, microns (0.001 mm)	% by wt in Gas Stream
	+60	60	41
-60	+40	50	11
-40	+30	35	8
-30	+20	5	10
-20	+15	17.5	7
-15	+10	12.5	6
-10	+7.5	8.75	5
-7.5		3.75	12

18. If a cinder recovery system is selected it should only collect cinders from boiler hoppers and air heater or economizer hoppers and should reinject them gently onto a quiet zone of the grate in order to minimize dust loading of combustion gases. Cinders from dust collector hoppers should be discharged to waste.
19. Automatic coal and ash-handling systems are essential for efficient operation of a steam plant. Both should be dust-proof and the coal-handling system should be capable of feeding slack coal with 10% moisture.
20. The automatic combustion control system should regulate forced and induced draft fan dampers according to steam pressure, furnace draft, and steam-flow-air-flow ratio. It should also provide remote manual control and hand-automatic transfer of total boiler load, coal feed and forced and induced draft fan dampers. The forced draft fan damper should have a minimum stop to assure that windbox pressure is never less than 0.2 in. water gauge, or more if required to prevent overheating of the grate. If steam is used to provide overfire turbulence it is desirable to control its flow according to smoke density.

Recommendations for Operation of Stoker Equipment

21. Cape Breton coal should be burned in thin fires. With the preferred spreader-fired continuous ash discharge grates, fire-beds should be 2 in. to 3 in. thick. On all other stokers they should be as thin as possible to ensure oxidizing conditions in the fire-bed thereby reducing both caking of the coal and clinkering of the ash.
22. CO₂ leaving the boiler should normally not exceed 11.9%. This represents about 150% total combustion air.
23. The fire on any grate should not be disturbed. Pokers and slice bars should not be used, except to gently pack coke formations as required to fill holes in a fire.
24. Undergrate air should never be shut off completely with a hot fire on a grate. The control drive on the forced draft fan dampers or louvers should be equipped with a minimum stop to provide at least 0.2 in. water gauge pressure under the grate as mentioned in Recommendation 20.
25. "On-off" operation of a stoker should be avoided as much as possible. This applies mostly to small underfeed stokers. At the time of writing an inexpensive control system is under development by the authors which, it is hoped, will minimize the operating difficulties resulting from "on-off" operation. It is described in a companion report previously mentioned dealing with small combustion equipment.

PULVERIZED AND CYCLONE-FIRED SYSTEMS

General

Modern conventional pulverized-fired boilers with large radiant furnaces are uniquely successful for burning Cape Breton coal, and only a few design features require careful attention.

Although relatively new, slagging combustion systems have also been successful. There are only two commercially available, one in which crushed coal of minus 1/8 in. size is burned in a cyclone, and the other, in which pulverized coal is burned by opposed, adjustable burners aimed downward over a quiescent slag pool.

Pulverized and cyclone-fired systems should be designed for lower quality coal than that specified for stoker design. The specification given in Table 3 may be considered typical.

TABLE 3

Coal Specification for Design of Pulverized and Cyclone-fired Systems

Sydney Area Fines, 1/4 in. x 0		As Received	Range to be Expected
<u>Proximate Analysis</u>			
Moisture	%	9.6	4.0 to 12.0
Volatile Matter	%	28.4	25.0 to 30.7
Fixed Carbon	%	46.0	43.7 to 53.5
Ash	%	16.0	10.3 to 16.0
Calorific Value,	Btu/lb	10,525	10,385 to 12,640
<u>Ultimate Analysis</u>			
Moisture	%	9.6	--
Ash	%	16.0	--
Carbon	%	58.5	--
Hydrogen	%	4.1	--
Nitrogen	%	1.2	--
Sulphur	%	4.8	--
Oxygen	%	5.8	--

Table 3 (continued)

Sydney Area Fines, 1/4 in. x 0	As Received	Range to be Expected
Ash Softening Temperature, °F	1,970	1,970 - 2,010
Free-swelling Index, ASTM	9.0	--
Caking Properties, (volatile matter residue, 950°C)	good	--
Grindability Index, Hardgrove	61	58 to 64

Recommendations for the Design of
Pulverized-fired and Slagging Systems

1. Gas temperature leaving the furnace should be at least 100°F below the ash softening temperature. Otherwise slag deposits may occur. Thus, for the coal specification given earlier the furnace exit temperature should not exceed 1,870°F.
2. Furnace heat liberation rate for continuous operation at 15% CO₂ should not exceed 84,000 Btu/sq ft of projected water-wall area/hr.
The rate may be increased somewhat for operation at less than 15% CO₂, but under no conditions should it exceed 90,000 Btu/sq ft of projected water-wall area/hr.
3. Final gas temperature is preferably no lower than 300°F at the lowest anticipated boiler rating. But more important is the metal temperature of the air preheater or economizer, whichever is last in the boiler circuit. For mild steel surfaces the metal temperature should be no lower than 280°F and for cast iron the metal temperature should be no lower than 200°F.

4. The temperature of the mixture leaving the pulverizer mill should not be less than 150°F when firing coal containing the maximum specified moisture.
5. For dry pulverized firing, coal should be ground to not less than 70% through a 200 mesh sieve and preferably 75% to 80% through a 200 mesh sieve. For pulverized firing of a slagging system, 50% through a 200 mesh sieve is adequate.
6. Gas velocity at the furnace exit should be low to prevent ash build-up on screen tubes or superheater tubes. The maximum allowable velocity depends somewhat on furnace exit temperature as well as the location and design of the superheater. In successful conventional boilers gas exit velocities are commonly 20 ft/sec.

CLOSURE

The rational application of the foregoing recommendations should provide satisfactory combustion systems for Cape Breton coal. In drafting specifications for a boiler or steam generator and its combustion system, giving the designer the greatest possible latitude commensurate with the quality range of the coal to be burned, will result in the most economical and workable plant, especially for pulverized-fired units and those with slagging combustion systems.

APPENDIX I

COMBUSTION CALCULATIONS, DOMINION SLACK, 3/4 in. x 0

Ultimate Analysis, lb/lb

Moisture	0.055
Carbon	0.710
Hydrogen	0.047
Oxygen	0.044
Nitrogen	0.013
Sulphur	0.028
Ash	<u>0.103</u>
Total.....	1.000 lb

Assume air at 80°F, 60% relative humidity, and 14.696 psia.

1. Stoichiometric air required

<u>Combustible</u>	<u>O₂ from air, lb</u>
C = 2.667 x 0.710	= 1.894 (CO ₂)
H ₂ = 8 x 0.047	= 0.376 (H ₂ O)
S = 1 x 0.028	= <u>0.028 (SO₂)</u>
Total	= 2.298
Less O ₂ in coal	= <u>0.044</u>
O ₂ from air, lb/lb coal	= <u><u>2.254</u></u>
Associated N ₂ = $\frac{76.85}{23.15} \times 2.254$	= <u><u>7.483</u></u>
Dry air, lb/lb coal	= <u><u>9.737</u></u>
Moisture in air = 9.737 x 0.0132	= <u><u>0.128</u></u>
Atmospheric air, lb/lb coal	= <u><u>9.865</u></u>

2. Stoichiometric products of combustion

<u>Dry</u>	<u>lb</u>
C = 0.710 + 1.894	= 2.604 (CO ₂)
N ₂ = 0.013 + 7.483	= 7.496 (N ₂)
S = 0.028 + 0.028	= <u>0.056</u> (SO ₂)
Dry flue gas, lb/lb coal	= <u>10.156</u>
<u>Wet</u>	
H ₂ O = 0.047 + 0.376	= 0.423 (H ₂ O)
Moisture in coal	= 0.055
Moisture in air	= <u>0.128</u>
Wet flue gas, lb/lb coal	= <u>10.762</u>

3. Combustion air for a range of total air

Specific volume of air = 13.89 cu ft/lb dry air.

Total air, %	100	120	140	160	180
Dry air, lb/lb coal	9.737	11.684	13.632	15.579	17.527
Atm air, lb/lb coal	9.865	11.838	13.811	15.784	17.757
Atm air, cu ft/lb coal	135.25	162.30	189.35	216.40	243.45

4. Products of combustion for a range of total air and temperature

At stoichiometric:

<u>Dry products</u>		<u>lb/lb coal</u>		<u>Mol wt</u>		<u>Mols</u>		<u>cu ft at 32°F</u>
CO ₂	=	2.604	÷	44	=	0.05918 x 359	=	21.24
N ₂ from coal	=	0.013	÷	28	=	0.00046 x 359	=	0.16
N ₂ from air	=	7.483	÷	28	=	0.26725 x 359	=	95.94
SO ₂	=	0.056	÷	64	=	0.00088 x 359	=	0.32
Dry flue gas	=	<u>10.156</u>				<u>0.32777</u>		<u>117.66</u>

Wet products

H ₂ O from coal and H ₂	=	0.478	÷	18	=	0.02656 x 359	=	9.54
H ₂ O from air	=	<u>0.128</u>	÷	18	=	0.00711 x 359	=	<u>2.55</u>
Wet flue gas	=	<u>10.762</u>						<u>129.75</u>

For 20% excess air

Additional O ₂ 0.2 x 2.254	=	0.451	÷	32	=	0.01409 x 359	=	5.06
Additional N ₂ 0.2 x 7.483	=	<u>1.497</u>	÷	28	=	0.05346 x 359	=	<u>19.19</u>
Additional dry products	=	<u>1.948</u>						<u>24.25</u>
Additional H ₂ O 0.2 x 0.128	=	<u>0.026</u>	÷	18	=	0.00144 x 359	=	<u>0.52</u>
Total	=	<u>1.974</u>						<u>24.77</u>

Total air, %	100	120	140	160	180
Dry flue gas, lb/lb coal	10.156	12.104	14.052	16.000	17.948
Dry flue gas, cu ft at 32°F/lb coal	117.66	141.91	166.16	190.41	214.66
Wet flue gas, lb/lb coal	10.762	12.736	14.710	16.684	18.658
Wet flue gas, cu ft at 32°F/lb coal	129.75	154.52	179.29	204.06	228.83

$$\text{Wet gas correction for } 300^{\circ}\text{F} = \frac{460 + 300}{460 + 32} = 1.54472$$

$$\text{" " " " } 350^{\circ}\text{F} = \frac{460 + 350}{492} = 1.64634$$

$$\text{" " " " } 400^{\circ}\text{F} = \frac{460 + 400}{492} = 1.74797$$

$$\text{" " " " } 450^{\circ}\text{F} = \frac{460 + 450}{492} = 1.84959$$

$$\text{" " " " } 500^{\circ}\text{F} = \frac{460 + 500}{492} = 1.95122$$

$$\text{" " " " } 550^{\circ}\text{F} = \frac{460 + 550}{492} = 2.05284$$

Total air, %	Wet flue gas, cu ft/lb coal						
	32°F	300°F	350°F	400°F	450°F	500°F	550°F
100	129.75	200.43	213.61	226.80	239.98	253.17	266.36
120	154.52	238.69	254.39	270.10	285.80	301.50	317.20
140	179.29	276.95	295.17	313.39	331.61	349.83	368.05
160	204.06	315.22	335.95	356.69	377.43	398.17	418.90
180	228.83	353.48	376.73	399.99	423.24	446.50	469.75

5. Per cent CO₂ for a range of total air (dry gas basis)

CO₂, cu ft at 32°F/lb coal = 21.24

Total air, %	100	120	140	160	180
Dry flue gas, cu ft at 32°F/lb coal	117.66	141.94	166.16	190.41	214.66
CO ₂ , %	18.05	14.96	12.78	11.15	9.90

6. Total air corresponding to round figures of per cent CO₂ (dry gas basis)

CO ₂ , %	Total Mols (1)	Mols excess air (2)	Excess air, lb (3)	Total air, % (4)
18.00	0.32878	0.00101	0.029	100.30
17.00	0.34812	0.02035	0.589	106.05
16.00	0.36988	0.04211	1.218	112.51
15.00	0.39455	0.06676	1.931	119.83
14.00	0.42271	0.09494	2.747	128.21
13.00	0.45523	0.12746	3.687	137.87
12.00	0.49317	0.16540	4.785	149.14
11.00	0.53800	0.21023	6.082	162.46
10.00	0.59180	0.26403	7.638	178.44

(1) $\frac{0.05918 \times 100}{\% \text{ CO}_2}$

(2) Total Mols - 0.32777

(3) Mols excess air x 28.93

(4) $100 + \frac{\text{wt excess air} \times 100}{9.737}$